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CA IOU Updated Information on Computer Monitors and Signage Displays

Additional submitted attachment is included below.

Electronic Displays

Codes and Standards Enhancement (CASE) Initiative
For PY 2015: Title 20 Standards Development

Response to CEC Staff Report for
Computer Monitors and Signage Displays

Docket #14-AAER-2

August 6, 2015

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1 Executive Summary

The Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), Southern California Gas (SCG), San Diego Gas & Electric (SDG&E) Codes and Standards Enhancement (CASE) Initiative Project seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (CEC) and other stakeholders in the development of these new and updated standards. This document provides recommendations and supporting analysis in response to the CEC's Staff Report.

Starting in July 2015, the CASE Team started working with a technical group, including representatives from the Information Technology Industry Council (ITI), electronic display manufacturers, and energy efficiency advocates to explore areas of a Title 20 standard where the groups could come to an agreement and present a joint proposal to CEC. At this time, it is in the early stages of the discussions and the technical group has only started getting into the details on some of the topics. As the discussions progress, we will have a better understanding if there are topics on which the technical group can come to agreement.

The comments below outline recommendations for improving, clarifying, and updating the proposed standards for electronic displays. Since there may be more recent data and information on some assumptions initially proposed in the 2013 CASE Report, the CASE Team outlined in this document updates CEC should consider for electronic displays based on more recent data. Electronic display standards if adopted as outlined in this letter would address some of the statewide policy objectives of Zero Net Energy California Long Term Energy Efficiency Strategic Plan and AB32 energy efficiency goals. We appreciate careful consideration of the following comments.

2 Enhanced Performance Displays (EPDs)

2.1 Background

EPDs are different from standard computer monitors in that EPDs have improved feature sets, which may include: increased color gamut, greater contrast ratios, better viewing angles, higher resolution, integrated accessories, and expansion potential. The CASE Team believes enhanced performance displays have characteristics that are likely to become more common in mainstream computer monitors in the near future such as high resolution and accurate color reproduction and therefore recommends the CEC include them in the scope of this rulemaking. In our testing and analysis of enhanced performance displays the CASE Team found that they require more power than standard computer monitors, but that there are opportunities for improvement similar to mainstream computer monitor.

Figure 2.1 shows the wide variation in the On Mode power draw among models qualified as ENERGY STAR. The data compiled by ENERGY STAR shows that **some EPD models can draw almost three times (or greater) more power in On Mode than similar-sized EPDs**. It is important to emphasize that these are ENERGY STAR qualified models. There are likely many other EPD models available on the market that draw much more power in On Mode and have not been reported to ENERGY STAR. Therefore the variation in On Mode power draw among similar sized equipment is likely much larger than displayed in Figure 2.1.

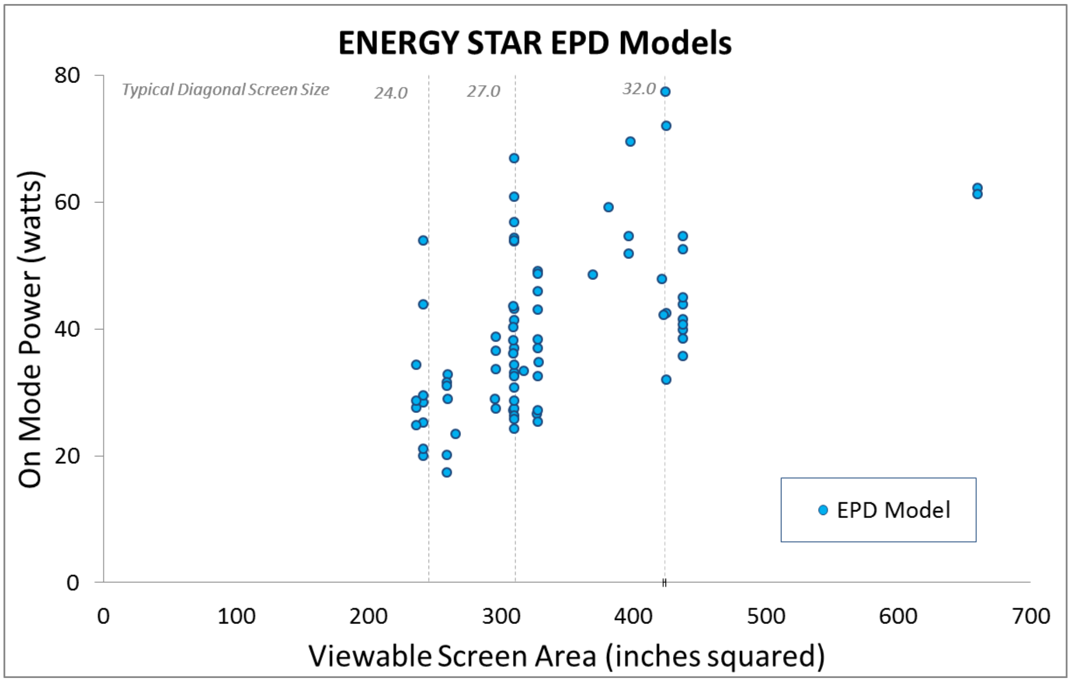

Figure 2.1 ENERGY STAR EPDs: Reported On Mode

Source: ENERGY STAR Version 7 Specification Development Dataset (July 2015)

Based on testing conducted by the CASE Team, we recommend establishing power adders to the calculated On Mode power limit for computer in order to account for additional power consumption due to enhanced capabilities of this equipment when compared to mainstream computer monitor. We recommend this power adder approach rather than exempting EPDs from these regulations since there is an opportunity for cost effective energy savings for these products. Additionally, through the specification development process with ENERGY STAR, the lines between EPDs and mainstream monitors are becoming indistinct. An exemption for EPDs could create an unintended loophole for mainstream monitors.

This "power adder" approach we continue to recommend is similar to the approach by EPA to address these products in the ENERGY STAR program. Figure 2.2 shows the EPDs model count by the date available on the market as reported by the manufacturers. The trend of increasing ENERGY STAR EPD models shows that energy efficient EPD models continue to be added to the market reflecting an opportunity for energy savings by establishing cost-effective standards for this product category and also reflecting that EPDs are not niche products.

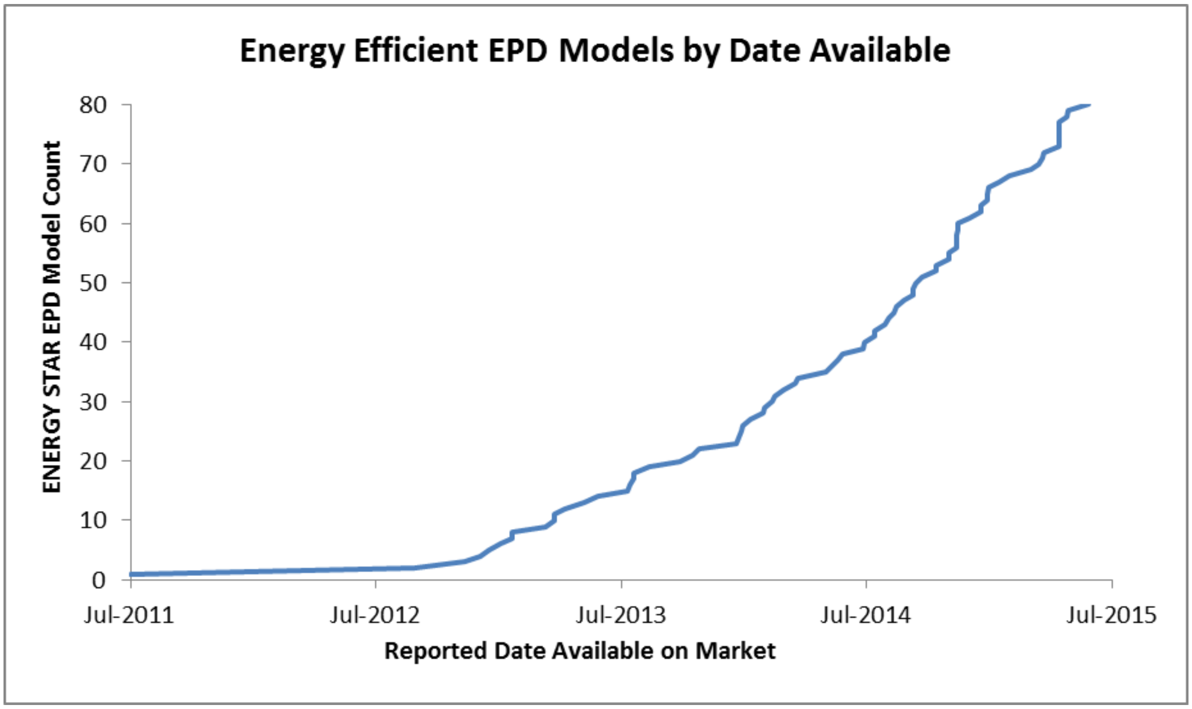

Figure 2.2 ENERGY STAR EPDs by Date Available

Source: ENERGY STAR Version 7 Specification Development Dataset (July 2015)

2.2 EPD Power Allowance

In the 2013 CASE Report, we proposed for products meeting the definition of an EPD a power allowance, similar to the ENERGY STAR Version 6 Specification, should be added to the On Mode power maximum. Since 2013, the CASE Team has conducted as-assembled and teardown testing to better understand the cost-efficiency relationship for EPDs to propose a standard level that is cost effective using readily available technologies.

Based on the extensive testing conducted by the CASE Team, the On Mode power allowance shown in Table 2.1 was determined to be cost-effective for EPDs. For products meeting the definition of an EPD, a power allowance (P_{EP}), similar to the ENERGY STAR Specification, shall be added to the On Mode power maximum as proposed by CEC in Table 5 the Staff Report (CEC 2015). In these cases, measured On Mode power (P_{ON}) shall be less than or equal to the sum of P_{EP} and P_{ON_MAX}. The power allowance (P_{EP}) shall be calculated using the following equations in Table 2.1 depending on the color gamut of the EPD. Extensive discussion, prepared by the CASE Technical Team, on EPD testing and analysis are presented in Appendix A.

Table 2.1 Calculation of On Mode Power Allowance for Enhanced Performance Displays

Color Gamut Criteria	On Mode Power Allowance in Watts (P_{EP})
Color Gamut support is 32.9% of CIE LUV or greater (99% or more of defined sRGB colors)	$0.15 * PON\_MAX$
Color Gamut support is 38.4% of CIE LUV or greater (99% of Adobe RGB)	$0.60 * PON\_MAX$

P_{ON_MAX} = On Mode Power in Watts

The CASE Team updated the proposed framework to use a color gamut criterion to determine the appropriate EPD power adder, aligning with the updated ENERGY STAR framework proposed in the development of the Version 7 specification. EPA found that for EPDs, holding resolution and area constant, increased color gamut performance typically requires more power. Models supporting 32.9% of CIE LUV (99% or more of defined sRGB colors) indicate a need for additional power over models with a smaller color space. Models covering at least 38.4% of CIELUV (99% of Adobe RGB)—an even higher coverage—appear to require more power (EPA 2015).

In reviewing the current ENERGY STAR Version 7 specification development dataset, 80 models were listed as being an EPD. Of those, over half, or 42 models, would be able to meet the On Mode levels proposed in the CEC Staff Report without any additional power adders. Because it is clear that for a significant percentage of the reported EPD models that are able to meet the On Mode levels without an additional power adders proposed in Table 2.1, CEC should consider phasing out the proposed power adders for EPDs 2 years after Title 20 standards take effect. This approach to sunset the power allowance also accounts for the fact that LED technology will continue to make significant improvements in the foreseeable future with respect to quality and efficiency.

3 Definitions

As mentioned earlier, the CASE Team is working closely with a technical group of stakeholders to identify areas of agreement and put forth joint proposals to CEC. At this time, the group is discussing applicable definitions. Until agreements are reached with the joint group, the CASE Team recommends CEC use the definitions proposed in the ENERGY STAR Final Draft Version 7 specification (EPA 2015a). Specifically, definitions should be adopted on product types, operational modes, visual characteristics, additional functions and features, product family, representative model, and power source. The definitions in the ENERGY STAR Version 7 specification are outlined in Appendix B of this letter.

In addition to the Version 7 definitions, we continue to support the use of the EPD definition outlined in in Section 2.1.1 of the CASE Report (CA IOUs 2013):

> *A computer monitor that has all of the following features and functionalities:*
>
> > *A contrast ratio of at least 60:1 measured at a horizontal viewing angle of at least 85°, with or without a screen cover glass;*

A native resolution greater than or equal to 2.3 megapixels (MP); and,

A color gamut size of at least sRGB as defined by IEC 61966 2-1. Shifts in color space are allowable as long as 99% or more of defined sRGB colors are supported.

EPA is expecting to finalize the Version 7 specification in August 2015. Once the specification is finalized, we will compare any updates to the definitions to ensure consistency. The definitions in the Version 7 specification have been thoroughly vetted by stakeholders through the ENERGY STAR specification development process.

4 Test Procedure

The CASE Team at this time continues to recommend On Mode testing for monitors without adjusting luminance or other settings from their default settings. Since most users likely do not adjust brightness settings from "out of the box" settings, this method is likely to be more representative of real world power usage than by calibrating the screen brightness to a certain level. By testing default settings, the State of California will be able to more accurately measure monitor energy usage that is more reflective of real-world conditions.

To address the concern voiced by manufacturers that their monitors would not be able to display a bright picture in retail settings, we recommend an approach that has been successful in addressing the same concern with regards to televisions. The Title 20 regulation for televisions allows for a retail mode that can be as bright as possible to compete in retail settings. The standards apply to the default, or the as-shipped luminance, mode. A similar provision could be applied to electronic displays. Also, since the current Title 20 television regulations and test procedures apply to signage displays currently being sold in California, this approach has been used with signage displays for several years.

In order to prevent manufacturers setting the default picture setting to an unacceptably low level in order to achieve a lower On Mode power measurement, the CASE Team suggests that the ratio of the default picture setting to the brightest picture setting be greater than or equal to 65 percent. This is a similar approach as outlined in the ENERGY STAR television specification and the Title 20 television regulations, which also requires On Mode testing to be conducted in the default setting. The CASE Team will continue to investigate alternative requirements to close any potential loopholes to the test procedure.

Industry representatives recommend the test procedure as adopted by the ENERGY STAR displays specification. The ENERGY STAR test procedure requires that display screen brightness be calibrated to 200 nits (candelas per meter squared) for On Mode testing and the default brightness can be set at any level. In our testing, the CASE Team found screen brightness values in default mode as-shipped to be significantly higher than 200 nits. This in turn has a significant impact on the backlight unit (BLU) power. Since most users likely do not adjust brightness settings from "out of the box" settings, this method is likely to be not representative of real world power usage. The test procedure is a topic of discussion for the technical group of various stakeholders. The CASE Team will continue investigating if the group can agree on a joint recommendation. In the meantime, the CASE Team recommends testing be conducted in the as-shipped, or default, settings.

5 Scope and Feasibility

5.1 Computer Monitors

The CASE Team continues to recommend that the scope of the Title 20 regulations include products that are in scope with ENERGY STAR and potentially exempt products that are out of scope with ENERGY STAR. The products that are exempted in ENERGY STAR include (EPA 2015a):

- Displays with integrated or replaceable batteries designed to support primary operation without ac mains or external dc power, or device mobility (e.g., electronic readers, battery powered digital picture frames); and
- Products that must meet Food and Drug Administration specifications for medical devices that prohibit power management capabilities and/or do not have a power state meeting the definition of Sleep Mode.

Scope is another topic of discussion for the technical group of various stakeholders. The CASE Team will continue investigating if the joint group can agree on a recommendation regarding scope based on market data to help inform decision on how the regulations should treat specialty products, like OLED monitors, professional display monitors, and outdoor signage displays.

5.1.1 Size Bins

The CASE Team initially supported the proposed size bin categorizations proposed by CEC in Table 5 of the Staff Report (CEC 2015) and listed in Table 5.1 below. These size bins were first established by EPA in the current ENERGY STAR Version 6 specification that has been in effect for over 2 years (EPA 2013).

Table 5.1 Screen Size Bins for Maximum Power Requirements – Computer Monitors

Diagonal Screen Size in Inches (*d*)
d < 12”
12” ≤ d < 17”
17” ≤ d < 23”
23” ≤ d < 25”
25” ≤ d < 61”

In regards to comments that CEC should reconsider the high-end of the size range, the CASE Team reviewed models available on the ENERGY STAR Qualified Product List (QPL) and identified six 55-inches models from four different manufactures that were listed as for sale in the United States (EPA 2015c). Though many of those 55-inch models appear to be mislabeled and should be listed as a signage display, there is at least one 55-inch computer monitor available by a major manufacturer

(Dell 2015). Since it is not clear that there is any size limitation with computer monitors, the CASE Team additionally recommends CEC consider no maximum size limitation for computer monitors to prevent potential regulatory loopholes given computer monitor models are already being sold at 55-inches.

5.1.2 On Mode Power Requirements

The CASE Team reviewed ENERGY STAR's QPL to address concerns by industry that monitors would not be able to meet the On Mode power requirements proposed by CEC. Table 5.2 below shows the number of models, number of manufacturers, and panel types of qualifying models from our review of the QPL. The information reported by manufacturers on the QPL is certified product data. As shown in Table 5.2, a wide range of models, manufacturers, and panels are represented in qualifying models available on the market today. These models have to make no additional modifications in order to meet CEC's proposed On Mode power requirements. This highlights the technical feasibility of CEC's proposal. It is important to note that all panel types are able to meet On Mode requirements in the most popular screen size bins. In reviewing a random sampling of the 193 models that are able to meet CEC's proposed On Mode requirements, the CASE Team was able to find multiple mainstream computer monitors in various sizes.

Table 5.2 Characteristics of Qualifying Models – Computer Monitors

Diagonal Screen Size in Inches (*d*)	Qualifying Models	Manufacturers Represented	Panels Types Represented
d < 12"	4	2	IPS, TN, VA
12" ≤ *d* < 17"	18	9	IPS, TN
17" ≤ *d* < 23"	39	18	IPS, TN, VA
23" ≤ *d* < 25"	44	14	IPS, TN, VA
25" ≤ *d* < 61"	88	17	IPS, TN, VA
Total	193	23	IPS, TN, VA

IPS: In-plane Switching; TN: Twisted Nematic; VA: Vertical Alignment

In addition to the models available today that would be able to meet CEC On Mode requirements, there are **220 additional models** that exceed the On Mode levels by only **10% or less**. Many of these non-qualifying models would have to employ relatively minor modifications in order to allow these models to meet the proposed On Mode requirements.

5.2 Signage Displays

5.2.1 Size

As we extensively outlined in Section 3 of our response to CEC standards proposal for displays (CA IOUs 2015), we strongly urge the CEC to apply regulations to all screen sizes of signage displays, including currently unregulated models greater than 1400 inches-squared (in-sq). Given 1) a significant percentage of the signage display market is greater than 1400 in-sq (14% of 2017 shipments and 30% of energy use) and 2) the testing and analysis the CASE Team has docketed showing the cost-effectiveness, CEC should use this rulemaking as an opportunity to realize significant energy savings for signage displays larger than 1400 in-sq.

5.2.2 On Mode Power Requirements

Also outlined in Section 3 of our response to CEC standards proposal for displays (CA IOUs 2015), an On Mode power limit more stringent than what is proposed in the CEC Staff Report is cost effective and technically feasible. We continue to recommend an On Mode equation for signage displays, outlined in Table 5.3, that accounts for luminance and screen area which aligns with the approach proposed by ENERGY STAR in the development of the Version 7 specification. Because of the broad range of applications for signage displays that require various levels of brightness to account for the relative brightness of the ambient conditions, from dimly lit conference rooms to public displays that may receive direct sunlight, we recommend that the CEC consider including screen luminance in any On Mode equation for signage displays. These conclusions were based on extensive testing and analysis conducted by the CASE Team and docketed with CEC.

Table 5.3 Maximum Power Requirements– Signage Displays All Screen Areas

Screen Size (area A in inches squared)	On Mode (W)
$A < 1400$ **and** $A \geq 1400$	$(4.5 \times 10^{-5} \times l \times A) + 70 \times \tanh(0.001 \times (A - 200)) + 20$

Where

A = Viewable screen area (square inches);

l = Maximum measured luminance in candelas per square meter

6 Computer Monitor Duty Cycle Update

The CASE Team supports the annual duty cycle for computer monitors presented in the CEC Staff Report using updated published data and presented in Table 6.1 below. The residential duty cycle was outlined from a recent industry study (Fraunhofer 2014). The commercial duty cycle was derived from another study (Navigant 2009). The shipment-weighted average of total hours a year in each mode based on the 2016 projected shipments to California by sector. The values in Table 6.1 reflect the latest or most robust studies and should be used in CEC's analysis moving forward. The annual duty cycle values recommended in the 2013 CASE Report should be updated to the values reflected in Table 6.1 as outlined in the CEC Staff Report.

Table 6.1 Annual Hours in Power Mode for Computer Monitors by Sector: CEC Staff Report

	On (hrs/yr)	Sleep (hrs/yr)	Off (hrs/yr)	Source
Residential	1,533	4,453	2,774	Fraunhofer 2014
Commercial	2,483	5,043	1,234	Navigant 2009
Shipment-Weighted Averages	**2,232**	**4,887**	**1,640**	Calculation

Note: Shipment-weighted averages do not add up to 8,760 (total number of hours in a year) due to rounding of calculated numbers.

7 Computer Monitor Installed Base Update

Similar to the annual duty cycle, the CASE Team supports the installed base values for computer monitors presented in the CEC Staff Report using updated published data and presented in Table 7.1 below. Estimates of installed base for California were calculated using national values presented in the published studies and assumed the share in California was 13.1 percent: the same percentage of California's share of the total U.S. GDP. The values in Table 7.1 reflect the latest or most robust studies and should be used in CEC's analysis moving forward. The installed based values recommended in the 2013 CASE Report should be updated to the values reflected in Table 7.1 as outlined in the CEC Staff Report.

Table 7.1 Computer Monitors Installed Base by Sector: CEC Staff Report

Sector	US Installed Base	CA Installed Base	Source
Residential	97,000,000	12,687,600	Fraunhofer 2014
Commercial	64,787,000	8,474,140	Navigant 2009
Total	**161,787,000**	**21,161,740**	

8 Computer Monitor Design Life Update

The CEC Staff Report references a design life of five years. The CASE Team recommends a longer design life highlighting a recent study from a group at Lawrence Berkeley National Laboratory (Park 2013). We corresponded with industry experts who noted that replacement cycles are more meaningful of an attribute, since many monitors can continue to work for 10 years or longer. We understand that the business markets monitor replacement cycles can be up to 6 years. We also understand residential products likely have longer lifetimes since they are used relatively less and consumers tend to replace a monitor only when it breaks or when there is a substantial improvement in technology. The CASE Team estimates the lifetime of a residential monitor to be 7 years, which reflects the high end of the range noted in the LBNL study. The installed base-weighted average across both sectors would be **6.6 years**. The design life recommended in the 2013 CASE Report should be updated to this value.

9 Other CASE Report Updates

9.1 Available Efficiency Strategies

Many of the efficiency strategies the CASE Team outlined in the 2013 CASE Report are further supported by a published study by the LBNL group entitled *Efficiency Improvement Opportunities for Personal Computer Monitors* (Park et al 2013). Section 7.4 of the CASE Report outlines numerous cost-effective strategies for meeting the proposed On Mode requirements, including improving backlight source, implementing optical films, improving the power supply, and employing dimming strategies. We support CEC referencing some of these design options in Chapter 12 of the CEC Staff Report. These design options should be considered when assessing the feasibility of the Title 20 regulation on computer monitors.

10 Further Research

10.1 Stakeholder Technical Group

There are several additional topics the technical group comprised of various stakeholders will be exploring in the coming weeks and potentially months. The topics include: additional power allowances in Off, Sleep, and/or On Modes, future proofing for new, undefined features, scope, feasibility, and test procedure. If possible, the CASE Team will seek towards developing joint proposals on these, or other, topics with the technical group to propose to CEC.

10.2 Cost Assumptions Updates

The CASE Team is attempting to obtain updated market data on pricing and forecasts for computer monitors and signage displays LCD backlights. Since cost estimates in the 2013 CASE Report included cost projections out to 2016 based on industry trends, purchasing additional market data may not be critical. In addition, the CASE Team has begun collecting retail cost data on computer monitors and signage displays and will be analyzing the data to support the cost-effective analysis the CASE Team has conducted previously.

10.3 Computer Monitors Resolution Adder Update

For LCDs, higher resolution to increase power draw is expected. Higher resolution means more pixels which increase the area of the electronics that control pixel operation, reducing the transmissivity of the panel. To maintain screen luminance, this requires increased output from the backlight which correlates to increased display power. However, based on the CASE Team's analysis, resolution does not necessarily scale linearly with size. This was the rationale for including a power adder for computer monitors based on resolution into any On Mode requirements. While we continue to support a resolution adder for mainstream monitors with a standard high definition resolution, given the availability of very high resolution models (e.g., 8.29 MP and 14.75 MP), we are continuing to investigate the appropriateness of the currently proposed adder for ultra-high definition models.

In one case, a higher resolution 27-inch model can consume almost five times as much power as the most efficient standard resolution 27-inch model and still meet the On Mode requirements. While that may be justified given the higher resolution, further analysis will be conducted to ensure On Mode requirements account for future trends to the extent possible. The computer monitor resolution may need to be reduced, or phased out, two years after the effective date for higher resolution models beyond the standard 2.1 megapixel models.

11 References

[CA IOUs] California Investor-Owned Utilities. 2014. Response to CEC Invitation to Submit Proposals. Codes and Standards Enhancement (CASE) Initiative: Title 20 Standards Development, Analysis of Standards Proposal for Electronic Displays. CEC Docket #12-AAER-2A. Dated June 29, 2013.

__. 2015. California IOUs Response to CEC Standards Proposal for Displays. CEC Docket #14-AAER-2. Dated May 29, 2015.

[CEC] California Energy Commission. 2015. *Presentation Computer Monitor and Signage Displays.* Staff Workshop: Computer Monitors and Signage Displays. May 16, 2015.

[Dell] Dell. 2011. "Dell 55 Monitor" http://www1.la.dell.com/vc/en/corp/peripherals/dell-e5515h/pd.aspx?refid=dell-e5515h&s=corp. Accessed on July 26, 2015.

[EPA] United States Environmental Protection Agency. 2015a. ENERGY STAR Program Requirements Product Specification for Displays Final Draft Version 7.0.Dated July 13, 2015.

__. 2015b. ENERGY STAR Version 7.0 Displays Final Draft EPA Masked Dataset. Dated July 13, 2015.

__. 2015c. ENERGY STAR Displays Qualified Product List. Dated July 22, 2015.

__. 2013. Final Version ENERGY STAR 6.0 Displays Program Requirements. Dated January 16, 2013.

[Fraunhofer] Fraunhofer Center for Sustainable Energy Systems. 2014. "Energy Consumption of Consumer Electronics in U.S. Homes in 20130". Dated June 2014.

[Navigant] Navigant Consulting, Inc. 2009. "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances". Final Report Dated December 21, 2009.

[Park et al] Won Young Park, Amol Phadke, Nihar Shah. 2013. "Efficiency improvement opportunities for personal computer monitors: implications for market transformation programs." Final Report Published January 23, 2013.

Appendix A Technical Memorandum

1 Background

This memo is intended to supplement the California IOUs' displays CASE report[1] and supplemental technical report[2]. These reports focused primarily on the testing and analysis of computer monitors and presenting cost-effective levels of power draw for on mode and sleep mode. During 2014, the CA IOU Technical Team had an opportunity to do a similar analysis for enhanced performance displays (EPDs). The CASE Technical Team is using the current comment period as an opportunity to present the findings.

An EPD is defined by ENERGY STAR Version 6 as a computer monitor that has all of the following features and functionalities:

- A contrast ratio of at least 60:1 measured at a horizontal viewing angle of at least 85º, with or without a screen cover glass;
- A native resolution greater than or equal to 2.3 megapixels (MP); and,

A color gamut size of at least sRGB as defined by IEC 61966 2-1. Shifts in color space are allowable as long as 99% or more of defined sRGB colors are supported.

For the Version 7 specification, ENERGY STAR removed EPDs as a defined product type and instead calls them out in the requirements section as computer monitors that meet a set of requirements similar to those above. The key changes are an allowance for curved screens on the measurement of contrast ratio and incorporation of the CIE standard for color gamut. 32.9% of CIE LUV (see bulleted list below) is equivalent to the Version 6 requirement of 99% of sRGB.

- Contrast ratio of at least 60:1 measured at a horizontal viewing angle of at least 85° from 209 the perpendicular on a flat screen and at least 83° from the perpendicular on a curved screen, with or without a screen cover glass;
- A native resolution greater than or equal to 2.3 megapixels (MP); and
- Color Gamut greater than or equal to 32.9% of CIE LUV.

2 Methodology

2.1 Test Unit Selection

We procured two EPDs to test and analyze – one pair of 27-inch displays. The models were selected to represent the range of energy efficiency of displays currently on the market. To isolate differences in power due to energy efficient designs rather than other features and functionality, the

[1] http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2A_Consumer_Electronics/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Electronic_Displays_2013-07-29_TN-71760.pdf

[2] http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2A_Consumer_Electronics/California_IOUs_Supplemental_Technical_Report_Electronic_Displays_2014-01-08_TN-72475.pdf

CASE Technical Team selected a pair of displays that had similar features but drew different amounts of power utilizing the ENERGY STAR® Qualified Product List (QPL). The representative model was chosen to represent a display of average energy efficiency; the efficient model represented one of the most efficient models available at the time of purchase. Considerations were also given to representing major display manufacturers. To better represent the market, each display was manufactured by a distinct, major display manufacturer.

2.2 As-Assembled Testing

The CASE Technical Team performed testing according to the ENERGY STAR Program Requirements for Displays – Test Method (Version 6.0 – Final, Jan-2013) for input power, luminance, illuminance, ambient temperature, relative humidity, power meter specifications and measurement accuracy. To warm up and stabilize each display before testing, the IEC 62087 dynamic broadcast-content video signal was used, which has an average picture level (APL) of 34% for a minimum of one hour. Test signals were generated by a computer then input to the displays using an interface cable such as HDMI, DVI or VGA.

Instantaneous luminance measurements were collected using the IEC 62087 3-bar static test signal in controlled darkroom conditions with the display in its as-shipped condition, with all user configurable options set to factory settings for default mode. Optional modes were tested in their default settings. Note that instantaneous power associated with each luminance measurement was logged, but used integrated power (described below) in the following analysis.

The CASE Technical Team performed on mode power testing according to the ENERGY STAR test method using guidance from IEC 62087, with the display in its as-shipped condition with all user-configurable options set to factory settings for default mode. Since ENERGY STAR requires EPDs be measured with luminance set at a value of 200 nits (candelas per square meter, or cd/m^2), each display was also tested in its default luminance settings to get a more accurate measurement of real world power draw. Additionally, optional picture modes in default settings and other picture features enabled were tested. Line power was measured every second during the 10-minute IEC 62087 dynamic broadcast-content video signal (IEC test clip) and averaged those measurements to obtain average power consumption.

Sleep mode testing was performed at factory default settings using guidance from IEC 62301: Household Electrical Appliances – Measurement of Standby Power.

2.3 Teardown Analysis

The purpose of the teardown analysis was to investigate power and optical systems to determine which components and designs produce more efficient displays. The CASE Technical Team targeted the investigation to include light processing components and lamps used in backlight units (BLUs). Although the computer monitor teardown analysis described in the 2013 CASE Report included power measurement of additional components, we determined that it would be more time and cost effective to focus on the most significant drivers of power draw.

The following information was collected:

- As-assembled and circuitry photographs: Documented the display and its components.
- BLU power draw: Used invasive techniques including modifying circuit boards, for in-circuit power measurements. A multi-channel power meter was spliced into the power

distribution circuits of the display under test. Power measurements were made using the 10 minute IEC video test clip and the 10-minute IEC internet test clip.

- Film characterization: Identified film types and the number of films in the stack.
- Optical film stack and LCD panel transmittance: Transmittance as the amount of light normal to the display that passes through each layer was measured. Each film sheet and the LCD panel have a gain or loss. Loss through the entire optical system is assessed by comparing the transmittance of light out of the LCD panel (normal to the display) to the power into the BLU.
- Micrographs of optical films and LCD panel: Identified film and panel types using a 300X digital microscope to view internal structures.
- Lamp count: Recorded number and size of the LEDs in the display.
- Lamp efficacy: Each display's LED strip was removed to test lamp efficacy in an integrating sphere. Lamp efficacy is a measure of the efficiency with which a lamp converts electrical energy into light energy, expressed in lumens per watt (lm/W). All lamp efficacies were determined using a Sphere Optics Model SLM-20 integrating sphere. The lamps were prepared for testing by attaching leads so that four of the lamps could be powered in isolation. Prior to removal, the CASE Technical Team determined the voltage per lamp that the display under test used to drive its BLU. The number of lamps energized was limited to prevent overheating with the lamp strip removed from its heat sink. The prepared LED assembly was placed in the integrating sphere with the lamps centered in the chamber. Lamp efficacy data were obtained while driving at the previously determined voltage per lamp and measuring the power input to the lamps being lit. Additional tests at lower driving voltages were also made to estimate what voltage produced the highest efficacy.

2.4 Cost Efficiency Analysis

To focus our efforts on the key components and approaches that most affect display energy use, the CASE Technical Team utilized lessons learned from testing and analysis completed in the 2013 CASE Report. We developed incremental costs for cost effective paths to efficiency improvement based largely on BLU power draw measurements and the efficiency with which the LCD panel and BLU manage light. We were able to use cost estimates from DisplaySearch for certain components including LEDs, optical films and backlight configurations. For other efficiency measures, such as implementation of light management approaches, we used industry expert estimates.

The CASE Technical Team used results from the teardown analysis to identify current technologies that may be used to improve energy efficiency, as well as market research to identify emerging technologies that may be available for future energy efficiency improvements.

3 Test Results and Analysis

3.1 As-Assembled Testing

Power and screen luminance test results for the two 27-inch test units are shown in the following table. The representative model (EPD27-1) had a default luminance of 245 candelas per meter squared (cd/m^2) and corresponding power of 56.1 Watt (W). The efficient model (EPD27-2) had a default luminance of 353 cd/m^2 and power of 40.9 W. The ENERGY STAR test method requires that average power be measured at a luminance of 200 cd/m^2. In this state, the representative and efficient displays drew less power than in their as-shipped conditions, 14% less for the representative model and 38% less for the efficient model.

The efficient display had user-selectable features that resulted in significantly lower power draw when enabled. With its "Eco" preset mode selected, the efficient model drew 49% less power. Its "CAD/CAM" preset mode resulted in a 28% decrease in power from its out of the box luminance and picture settings. The representative model also decreased power draw when certain preset picture modes focused on color gamut were selected such as DCI P3 (61% less) and BT.709 (45% less). In sleep mode, the representative and efficient displays drew the same power - 0.4 W.

Table 3.1 Power and Screen Luminance Testing Results

Source: CASE Team analysis

Display ID	Input Port	Test Description	Display Mode	Screen Luminance (cd/m2)	Power (W)
EPD27-1 Representative	HDMI	Default	sRGB D65	245.5	56.1
		200 nits	sRGB D65	200.4	48.5
		sRGB D50	sRGB D50	245.1	60.7
		Adobe RGB	Adobe	244.4	55.9
		BT.709	BT.709	98.0	30.9
		BT.2020	BT.2020	96.9	30.8
		DCI P3	DCI P3	45.5	21.8
		Native	Native	268.4	60.2
		Sleep (Sleep Source)	sRGB D65	-	0.4
		Sleep (Disconnect Source)	sRGB D65	-	0.4
		Off	sRGB D65	-	0.4
EPD27-2 Efficient	HDMI	Default	standard	353.1	40.9
		200 nits	standard	198.9	25.2
		sRGB	sRGB	321.7	37.9
		CAD/CAM	CAD/CAM	278.2	29.5
		Animation	Animation	319.3	37.8
		Presentation	Presentation	391.4	41.0
		Low Blue Light	Low Blue Light	235.6	29.3
		Movie	Movie	393.1	40.7
		Photo	Photo	381.6	40.7

Eco	Eco	232.6	20.7
M-book	M-book	380.1	40.7
Sleep (Sleep Source)	standard	-	0.4
Sleep (Disconnect Source)	standard	-	0.4
Off	standard	-	0.4

As with the computer monitors tested for the CASE report, average power consumption increased approximately linearly with screen luminance (Figure 3.1 below). This suggests that the majority of power draw variability is related to producing light and generating an image on the screen. Signal processing and other functions draw relatively constant power, as compared to screen brightness, when the display is showing a picture.

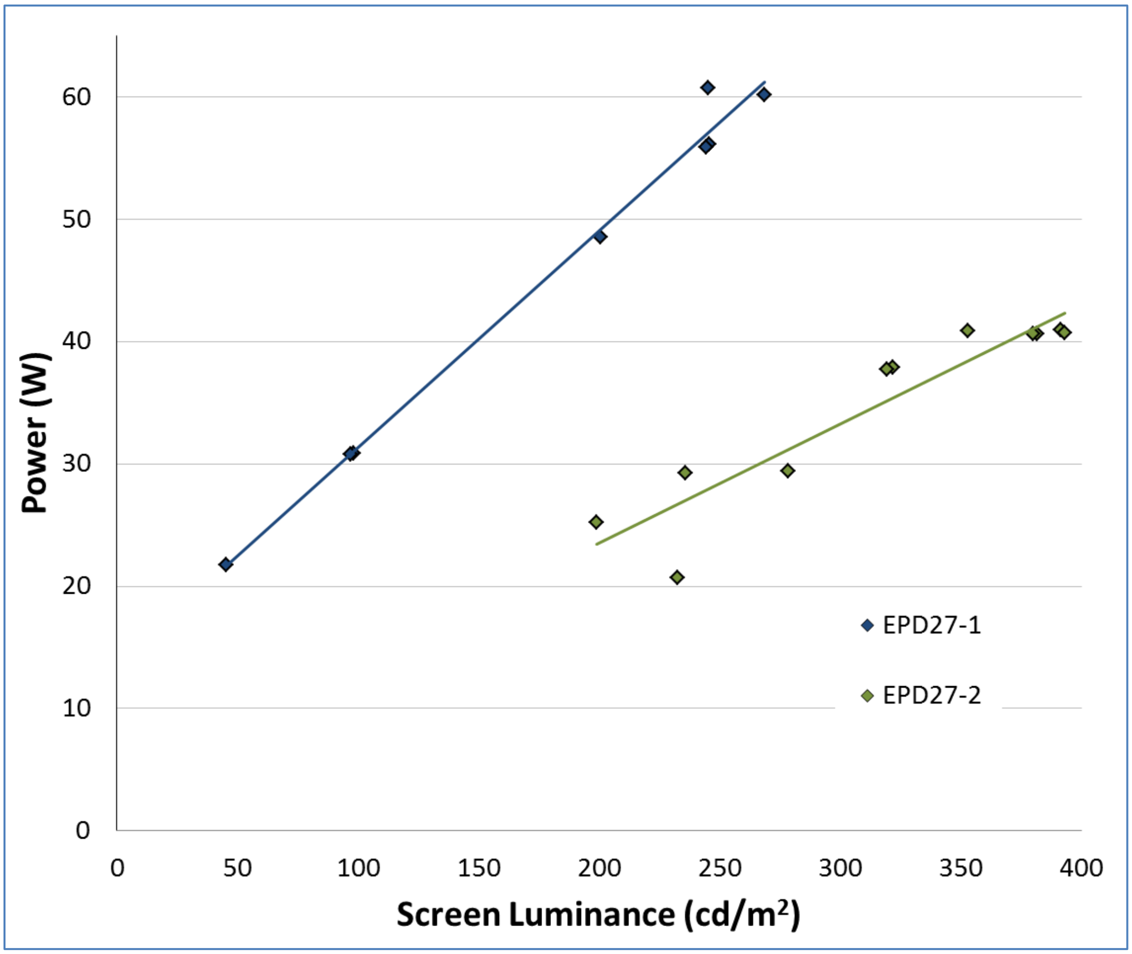

Figure 3.1 Screen Luminance versus Power for the Representative and Efficient Test Units in Various Settings (lines are linear fits to the data)
Source: CASE Team analysis

3.2 Teardown Analysis

Table 3.2 below presents the details for each signage display model that was included in the teardown analysis.

Table 3.2 Key teardown analysis findings for the EPD test units
Source: CASE Team analysis

ID	EPD27-1	EPD27-2
Panel type	IPS	IPS
Edge-lit or array	Edge-lit	Edge-lit
Number of LEDs	80	68
in^2/W default	5.5	7.6
LED efficacy (lm/W)*	46.0*	112.0
Film stack:	Y	Y
diffuser 1		
horizontal prism	Y	Y
vertical prism	N	N
diffuser 2	N	N
reflective polarizer	Y	Y
BLU efficiency (cd/W)	47.6	70.6
Panel transmissivity %	3	3

* Efficacy for EPD27-1 utilized green and magenta colored LEDs, presumably to enable its ability to achieve a greater color gamut (AdobeRGB).

3.2.1 BLU Power

As part of the testing of EPDs, the CASE Technical Team measured the power draw of the BLU as well as the total power draw for each display in its default and power saving mode by logging component-level power during the IEC video and internet test clips. The backlight unit accounts for the majority of a display's power budget with more efficient designs reducing the percent of power draw used by the backlight. For both displays, the representative and efficient models showed similar BLU percentages in their default modes (Table 3.3). However, each display measured a significantly lower BLU percentage when measured in its power saving mode (Figure 3.2).

Table 3.3 Percent Average Power Draw for Display Components
Source: CASE Team analysis

Display Mode	ID	BLU (W)	LCD, PS losses, Other (W)	BLU %
Default Mode	EPD27-2	24.2	16.9	59%
	EPD27-1	34.0	22.4	60%
Power Saving Mode	EPD27-2	7.1	13.8	34%
	EPD27-1	5.0	16.8	23%

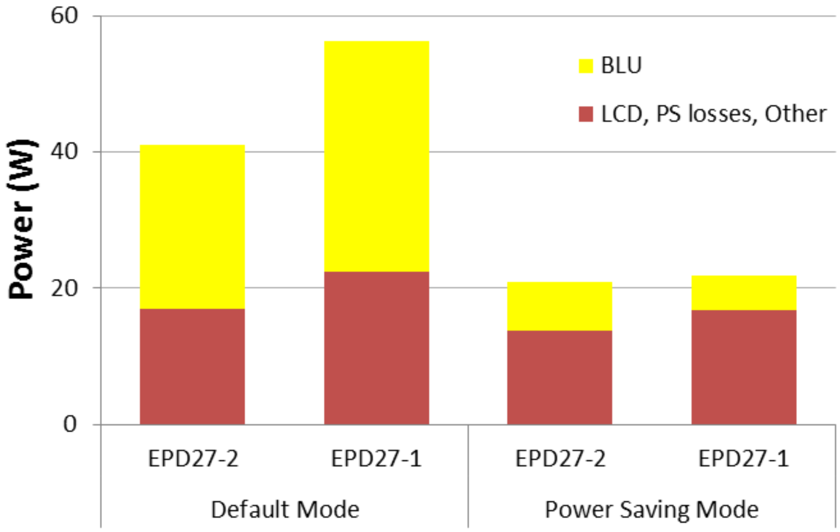

Figure 3.2 Tested Backlight Unit Power Draw
Source: CASE Team analysis

To further investigate BLU efficiency, we examined the instantaneous power measured during the test clips which shows how the power of the backlight scales to the content displayed. Displays that scale effectively will show lower power draw during the darker scenes of the test clip and high power draw during brighter scenes, saving energy use overall. For both displays, there was no scaling of the backlight to content in default mode, indicating that power draw reductions are due to dimming of the backlight overall and little else. However, in its Eco preset mode, the efficient model showed an ability to scale its BLU to video content (Figure 3.3). The representative model showed no scaling in its lower power draw modes.

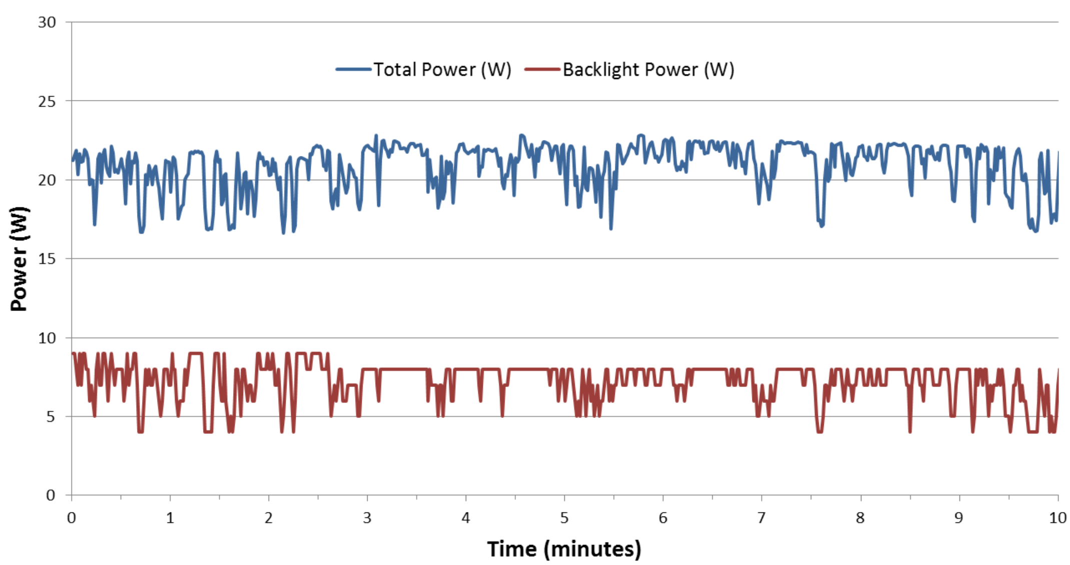

Figure 3.3 Instantaneous power measurements for EPD27-2 indicate an ability to scale its backlight to light or dark scenes in the IEC test clip

3.2.2 Lamp Efficacy

The lamp efficacies for each display were quite different, 46 lm/W (EPD27-1) versus 112 lm/W (EPD27-2). This difference was likely due to the different colored LEDs (green and red/magenta) used in the representative model (EPD27-1). The CASE Technical Team understands that these are used to create a higher color gamut display output, such AdobeRGB. However, it should be noted that the efficient model, which used highly efficient white/blue LEDs, was capable of creating the DCI P3 color gamut which is very close to the AdobeRGB color gamut (Figure 3.4).

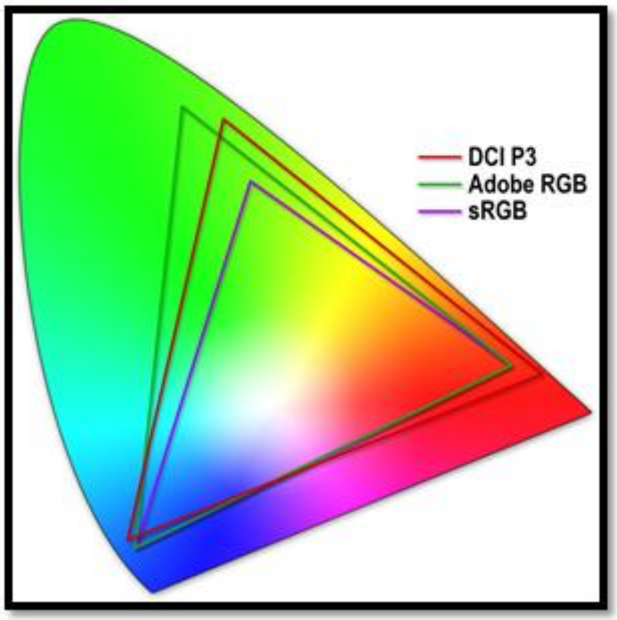

Figure 3.4. Comparison of Color Gamuts.

3.2.3 Backlight Unit On-Axis Efficiency

We calculated backlight unit on-axis efficiency as the screen-normal light output divided by the backlight power input. As explained in the CASE report, usable, screen-normal light is measured as the luminance of light directed normal to the display's screen. As light passes through a display's optical components, it is focused and oriented to be usable once it hits the LCD panel. For the units tested, the efficient model (EPD27-2) demonstrated a higher on-axis efficiency than the representative model. This is likely mainly due to the difference in LED efficacy since the film stacks and panel transmissivities are essentially the same. For more explanations of the different film types, please see the IOU displays supplemental Technical Report.

3.2.4 LCD Panel Transmissivity

LCD transmissivity is the ratio of screen-normal light measured out the front of the LCD panel to the screen-normal light measured out the front of the film stack, indicating how efficiently light passes through the LCD panel. Both models tested showed a relatively low efficiency (3%).

4 Cost-Efficiency Analysis

4.1 Efficiency Improvement Measures

4.1.1 LED Improvements

Because the representative test unit used the colored LEDs and therefore had a much lower efficacy measurement than more standard LEDs used for computer monitors, we modeled/calculated the impact of two approaches to LED improvement. The first approach presumes an overall efficacy improvement of 10% for the red and green LEDs, in line with amount of year to year increase attributed to more standard LEDs as market analysts have predicted a continued trend toward higher efficacy, lower cost LEDs. Costs for these lamps were estimated from discussions with industry experts based on DisplaySearch costs for slightly lower performance lamps. The second approach involves using standard 110 lm/W white/blue LEDs combined with quantum dots to create a capacity to output high color gamut such as AdobeRGB (see Section 4.1.2 below).

4.1.2 Quantum Dots

At the time of the CASE report, we considered quantum dots an emerging technology, however, they have since become widely available and from multiple suppliers[3]. Quantum dots are very tiny particles that can emit light at very specific wavelengths. Used in conjunction with an LCD panel's color filter, they can theoretically produce red, blue and green light more efficiently and with a greater color gamut than current displays. The increased efficiency comes in part from using current (blue light emitting) LEDs without a phosphor coating that creates white light.

The representative EPD used low efficacy, green and red colored LEDs to enable its ability to produce an Adobe RGB color gamut. We believe it is technically feasible to replace these colored LEDs with high efficacy LEDs paired with quantum dot film and still maintain an AdobeRGB color gamut. From a recent white paper developed by 3M:

> *For larger color gamut (for example: Adobe RGB or DCI P3), the energy-saving benefit of quantum dot technology is even more pronounced. One alternative method for an LCD to express these larger gamut is through the use of more saturated and less transmissive color filters. Because these filters block more light, the displays require much brighter backlight illumination, which requires more power. Compared to displays using these more saturated color filters, quantum dot displays with more typical color filters (e.g., CF72) can be up to 50 percent more energy-efficient in expressing these larger color gamut.*[4]

The CASE Technical Team was not able to acquire an accurate estimate of the cost of adding quantum dots or quantum dot film, so we determined what cost limit is possible while still making the improvement measure cost-effective. We calculated that cost limit to be $50, making this a likely a very cost-effective measure.

4.1.3 Backlight Dimming to Video Content

Dimming (also referred to as global dimming) reduces the light output and therefore power of a display based on the relative brightness of the video content. As noted in the BLU power section

[3] http://www.wired.com/2015/01/primer-quantum-dot/

[4] http://multimedia.3m.com/mws/media/985375O/3mtm-quantum-dot-enhancement-film-qdef-white-paper.pdf?fn=Quantum%20Dot%20QDEF%20Whitepaper.pdf

above, EPD27-2 demonstrated this capacity. From the computer monitors study in the CASE report, power savings with dimming enabled using the IEC video clip were 35% and 40% for the 22" and 27" models respectively. For this analysis, a conservative power reduction of 30% was used and applied to the representative unit.

Through consultation with industry experts, costs for dimming to video content were estimated to be minimal. The need to interpret signal picture levels and apply them to backlight output may require a slightly higher processing capability, so an incremental cost of $1 was used for implementation of dimming to content.

4.1.4 Reduce Screen Brightness

Although the ENERGY STAR test procedure requires calibration of units to 200 nits (candelas per square meter), our test data shows that this method is not representative of real world power usage. Reducing default, or "out of the box" luminance is a zero cost approach to reducing on mode power draw as long as the test procedure calls for units be tested in their default state.

4.2 Cost-Effective Approaches

The select individual efficiency measures described above were combined to generate three cost-effective measures for each size analyzed (Figure 4.1 below). To determine if a scenario was cost effective, the CASE Technical Team calculated the lifetime energy savings of the modeled more efficient display over the representative model and compared that to the incremental cost of the efficiency improvement. Cost effectiveness was calculated using 2016 costs. As noted in the CASE report, costs generally decrease over time, making analyses of the same scenarios for future years result in even further cost effectiveness. Details regarding which efficiency measures Table 4.1 below.

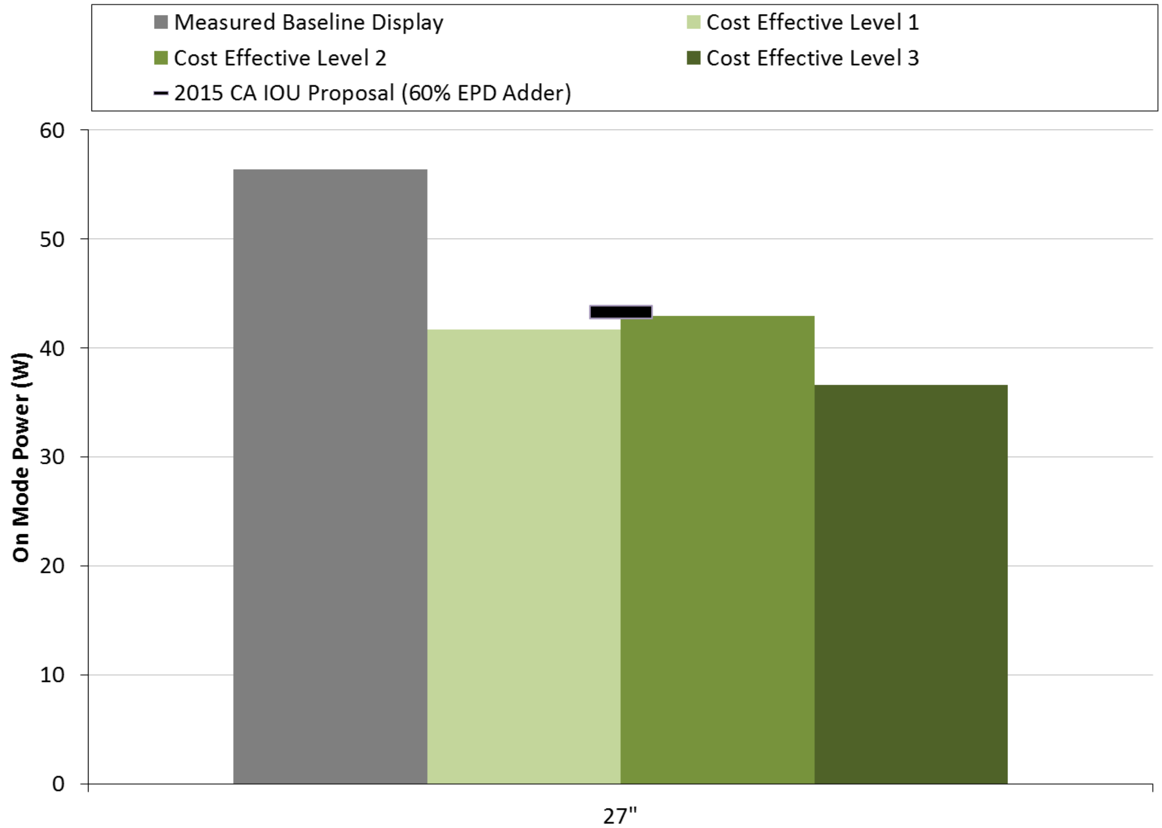

Figure 4.1. Cost Effective Approaches to Meet on Mode Power Limits
Source: CASE Team analysis

Table 4.1 Description of Cost Effective Strategies to Meet On Mode Power Limits
Source: CASE Team analysis

	Representative Model Attributes	Cost Effective Level 1	Cost Effective Level 2	Cost Effective Level 3
27"	On Mode: 56.4 W Reflective Polarizer: Yes Lamp Efficacy (LED): 46 lm/W Screen Brightness: 245 nits Global Dimming: No ABC: No Quantum Dot Film: No	On Mode: 41.7 W Reflective Polarizer: Yes Lamp Efficacy (LED): 51 lm/W Screen Brightness: 200 nits Global Dimming: Yes ABC: No Quantum Dot Film: No	On Mode: 42.9 W Reflective Polarizer: Yes Lamp Efficacy (LED): 51 lm/W Screen Brightness: 245 nits Global Dimming: Yes ABC: Yes Quantum Dot Film: No	On Mode: 36.6 W Reflective Polarizer: Yes Lamp Efficacy (LED): 110 lm/W Screen Brightness: 245 nits Global Dimming: No ABC: No Quantum Dot Film: Yes

Through the testing and teardown analysis of two EPDs, the CASE Technical Team was able to demonstrate multiple paths to cost-effectively reduce energy use. Approaches include improved lamp efficacy, the use of quantum dots, and dimming screen brightness to video content.

Appendix B Definitions

[Definitions from ENERGY STAR begin on next page.]

ENERGY STAR® Program Requirements
Product Specification for Displays

Eligibility Criteria
Final Draft Version 7.0

Following is the ENERGY STAR product specification ("specification") for Displays. A product shall meet all of the identified criteria if it is to earn the ENERGY STAR.

1 DEFINITIONS

A) Product Types:

1) Electronic Display (Display): A product with a display screen and associated electronics, often encased in a single housing, that as its primary function produces visual information from (1) a computer, workstation, or server via one or more inputs (e.g., VGA, DVI, HDMI, DisplayPort, IEEE 1394, USB), (2) external storage (e.g., USB flash drive, memory card), or (3) a network connection.

a) Monitor: An electronic display intended for one person to view in a desk based environment.

b) Signage Display: An electronic display intended for multiple people to view in non-desk based environments, such as retail or department stores, restaurants, museums, hotels, outdoor venues, airports, conference rooms or classrooms. For the purposes of this specification, a display shall be classified as a signage display if it meets two or more criteria listed below:

(1) Diagonal screen size is greater than 30 inches;

(2) Maximum Reported Luminance is greater than 400 candelas per square meter;

(3) Pixel density is less than or equal to 5,000 pixels per square inch; or

(4) Ships without a mounting stand.

Note: In Draft 2, EPA proposed distinguishing a signage display using three criteria: screen size, Maximum Reported Luminance, and pixel density. Given a stakeholder comment that there still may be overlap among two or more of these criteria, EPA is proposing a fourth criterion based on the physical configuration of a product to reflect the typical use cases for signage displays. Most signage displays are wall-mounted as opposed to stand-mounted like computer monitors. Therefore, EPA has added the additional criterion "ships without a mounting stand" to further delineate the product types. As such, EPA now proposes a set of four criteria, where a display would have to meet at least two to be classified as a signage display.

B) Operational Modes:

1) On Mode: The mode in which the display has been activated, and is providing the primary function.

2) Sleep Mode: A low-power mode in which the display provides one or more non-primary protective functions or continuous functions.

Note: Sleep Mode may serve the following functions: facilitate the activation of On Mode via remote switch, internal sensor, or timer; provide information or status displays including clocks; support sensor-based functions; or maintain a network presence.

3) Off Mode: The mode where the display is connected to a power source, produces no visual information, and cannot be switched into any other mode with the remote control unit, an internal signal, or an external signal.

Note: The display may only exit this mode by direct user actuation of an integrated power switch or control. Some products may not have an Off Mode.

C) Visual Characteristics:

1) Ambient Light Conditions: The combination of light illuminances in the environment surrounding a display, such as a living room or an office.

2) Automatic Brightness Control (ABC): The self-acting mechanism that controls the brightness of a Display as a function of Ambient Light Conditions.

Note: ABC functionality must be enabled to control the brightness of a Display.

3) Color Gamut: Color gamut area shall be reported as a percentage of the CIE LUV 1976 *u*' *v*' color space and calculated per Section 5.18 Gamut Area of the Information Display Measurements Standard Version 1.03.

Note: Any gamut support in non-visible/invisible color areas is not to be counted. The gamut's size must be expressed as a percentage of area of the visible CIE LUV color space only.

4) Luminance: The photometric measure of the luminous intensity per unit area of light travelling in a given direction, expressed in candelas per square meter (cd/m^2).

a) Maximum Reported Luminance: The maximum luminance the display may attain at an On Mode preset setting, and as specified by the manufacturer, for example, in the user manual.

b) Maximum Measured Luminance: The maximum measured luminance the display may attain by manually configuring its controls, such as brightness and contrast.

c) As-shipped Luminance: The luminance of the display at the factory default preset setting the manufacturer selects for normal home or applicable market use.

5) Native Vertical Resolution**:** The number of physical lines along the vertical axis of the Display within the visible area of the Display.

Note: A display with a screen resolution of 1920 x 1080 (horizontal x vertical) would have a Native Vertical Resolution of 1080).

6) Screen Area: The visible area of the display that produces images.

Note: Screen Area is calculated by multiplying the viewable image width by the viewable image height. For curved screens, measure the width and height along the arc of the display.

D) Additional Functions and Features:

1) Bridge Connection: A physical connection between two hub controllers (i.e., USB, FireWire).

Note: Bridge Connections allow for expansion of ports typically for the purpose of relocating the ports to a more convenient location or increasing the number of available ports.

2) Full Network Connectivity: The ability of the display to maintain network presence while in Sleep Mode. Presence of the display, its network services, and its applications, is maintained even if some components of the display are powered down. The display can elect to change power states based on receipt of network data from remote network devices, but should otherwise stay in Sleep Mode absent a demand for services from a remote network device.

Note: Full Network Connectivity is not limited to a specific set of protocols. Also referred to as "network proxy" functionality and described in the Ecma-393 standard.

3) Occupancy Sensor: A device used to detect human presence in front of or in the area surrounding a display.

Note: An Occupancy Sensor is typically used to switch a Display between On Mode and Sleep Mode.

4) Touch Technology: Enables the user to interact with a product by touching areas on the Display screen.

5) Plug-in Module: A modular plugin device that provides one or more of the following functions without the explicit purpose of providing general computing function:

a) Display images, mirror remote content streamed to it, or otherwise render content on the screen from local or remote sources; or

b) Process touch signals.

Note: Modules providing additional input options are not considered Plug-in Modules for the purposes of this specification.

E) Product Family: A group of product models that (1) are made by the same manufacturer, (2) share the same Screen Area, Resolution, and Maximum Reported Luminance, and (3) are of a common basic screen design. Models within a Product Family may differ from each other according to one or more characteristics or features. For displays, acceptable variations within a Product Family include:

1) External housing;

2) Number and types of interfaces;

3) Number and types of data, network, or peripheral ports; and

4) Processing and memory capability.

F) Representative Model: The product configuration that is tested for ENERGY STAR certification and is intended to be marketed and labeled as ENERGY STAR.

G) Power Source

1) External Power Supply (EPS): An external power supply circuit that is used to convert household electric current into dc current or lower-voltage ac current to operate a consumer product.

2) Standard dc: A method for transmitting dc power defined by a well-known technology standard, enabling plug-and-play interoperability.

Note: Common examples are USB and Power-over-Ethernet. Usually Standard dc includes both power and communications over the same cable, but as with the 380 V dc standard, that is not required.